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Papillomatous digital dermatitis and associated risk factors in US dairy herds

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Abstract

The objective of this study was to describe the incidence of papillomatous digital dermatitis in the US (including regional and herd size patterns) and to evaluate specific herd-level management factors associated with high incidence of digital dermatitis in US dairy herds. The study design was a population-based cross-sectional survey. US dairy operations with at least 30 cows in 20 states, representing 79% of US dairy cows, were sampled. On participant operations, a questionnaire was administered by veterinary medical officer or animal-health technicians on-farm to dairy managers.

Papillomatous digital dermatitis was reported in milk cows in the previous 12 months from 43.5% of US dairy herds. Seventy-eight percent of affected herds reported that their first cases occurred in 1993 or later. Regions of the USA with the highest percent of herds affected included the Southwest, Northwest, and Northeast. Factors associated with high (>5%) incidence of papillomatous digital dermatitis included region, herd size, type of land lactating cows accessed on a daily basis, flooring type where lactating cows walked, percent of cows born off the operation, use of a primary hoof trimmer who trimmed cows' hooves on other operations, and lack of washing of hoof-trimming equipment between cows.

Papillomatous digital dermatitis has been recently reported from dairy herds across the US. This study suggests that a high percentage of herds with digital dermatitis could be prevented. Management strategies to potentially prevent or reduce incidence of digital dermatitis on dairy operations include those related to biosecurity and 'cow hoof' environmental conditions. Published by Elsevier Science B.V.

Keywords: Digital dermatitis; Footwarts; Cattle – microbiological diseases

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1. Introduction

Papillomatous digital dermatitis (digital dermatitis or footwarts) is an emerging disease condition in dairy cows. It was first reported in Italy in 1974 (Cheli and Mortellaro, 1974) and since that time has been reported from countries around the world (Blowey and Sharp, 1988). In the USA, the disease was first reported as lameness outbreaks in New York dairy herds (Rebhun et al., 1980) and over the last decade has been recognized as an important cause of bovine lameness (Read et al., 1992).

Clinically, digital dermatitis typically appears within dairy herds as lameness outbreaks of variable severity. It is a superficial skin disease of the bovine digit with variable presentation (depending upon the stage of the lesion), from painful, moist, strawberry-like lesions to raised, hairy, wart-like lesions (Read and Walker, 1998). These lesions (usually located on the rear of the foot between the bulbs of the heel) have been referred to by several names, including: 'hairy footwarts', 'strawberry (or raspberry) heelwarts', and 'papillomatous digital dermatitis'. Early lesions usually respond to topical antibiotic treatment (although they may recur later).

The economic impact of digital dermatitis within dairy herds has not been well-defined to date. High morbidity seen in some herds – and the resulting severe lameness in affected cows with associated losses in milk production, reproductive efficiency, bodyweight, and treatment costs – create substantial losses for affected dairy producers (Rebhun et al., 1980; Nutter and Moffitt, 1990). A study from a Mexican herd with 33% of cows affected during lactation reported a 20 day increase in calving-to-conception interval (Argaez-Rodriguez et al., 1997).

The cause of digital dermatitis is not yet fully understood; aspects of the host–agent–environment complex have been studied. California researchers have isolated two separate spirochete bacteria from footwart lesions and have concluded that these spirochetes are most similar to *Treponema* (Walker et al., 1995). While they have not been able to reproduce the disease from the isolated organisms, their work is ongoing. Those researchers suggest that digital dermatitis is a contagious disease (based upon spread of disease regionally, high levels of disease within affected herds, within-herd spread after introduction of affected cattle, and higher prevalence in younger cows) (Read and Walker, 1998). Research on environmental predispositions of digital dermatitis has suggested that certain herd-level or management practices predispose dairy herds to infection. These factors include large herd size, moisture of corrals where cows walk, and introduction of dairy replacement heifers to the operation (Rodriguez-Lainz et al., 1996a, b). Increased understanding of causal factors for this disease would facilitate development of management strategies to prevent or minimize disease and resulting economic losses.

Objectives of this study were to (1) describe the incidence of digital dermatitis in the US including regional and seasonal distributions and (2) evaluate specific herd-level management factors associated with high (>5%) incidence of digital dermatitis in US dairy herds.

2. Methods

The National Animal Health Monitoring System (NAHMS) Dairy '96 Study, conducted by the US Department of Agriculture:Animal and Plant Health Inspection Service:Veterinary Services (USDA:APHIS:VS), was designed to provide information on the national dairy herd for research and educational purposes. Study objectives were defined using a needs-assessment process involving focus groups that represented US dairy producers, veterinarians, dairy scientists, allied industries, and USDA:APHIS. One area prioritized during this process was to gather information to support farm-level preventive strategies for papillomatous digital dermatitis.

The first phase of the Dairy '96 Study was designed in collaboration with USDA:National Agricultural Statistics Service (NASS). A stratified-random sample of 4516 dairy producers in 20 states was selected from the NASS list frame. These 20 states represented 83% of US dairy cows in January 1995. During the first phase, NASS enumerators contacted dairy producers in January 1996 and administered a questionnaire assessing dairy health and management (National Animal Health Monitoring System, 1996). Study participation was voluntary for producers and individual producer information remained confidential. Each producer with at least 30 dairy cows that completed the questionnaire was asked to participate in the second phase of the NAHMS Dairy '96 Study. Operations with 30 or more cows represented 79% of US dairy cows.

Names of those producers willing to participate in the second phase of the study were released by NASS to USDA:APHIS. At this phase, each producer was contacted by APHIS or State veterinary medical officers or animal-health technicians for a second herd visit that was held during the period from February 20 through May 24, 1996. During this herd visit, dairy producers completed a second questionnaire which included questions regarding digital dermatitis. To assess incidence of digital dermatitis (as reported by dairy managers retrospectively), data collectors provided a brief, standardized description of the disease and showed several photographs of footwart lesions from a bulletin provided by University of California at Davis researchers (Read and Walker, 1995).

After data collection, questionnaires were checked by interviewers who provided an assessment of data quality. Study coordinators in each state and the Centers for Epidemiology and Animal Health performed additional data-quality assessments, data checks, and edits.

Northeast – New York, Pennsylvania, and Vermont
Southeast – Florida, Kentucky, and Tennessee
Midwest –
  North Midwest – Michigan, Wisconsin, and Minnesota
  South Midwest – Illinois, Indiana, Iowa, Missouri, and Ohio
West –
  Northwest – Idaho, Oregon, and Washington
  Southwest – California, New Mexico, and Texas

2.1. Descriptive analysis

For computation of point estimates of digital-dermatitis incidence, weights representing the inverse of the sampling fraction for each dairy operation (and adjusted for

producer nonresponse) were used. Statistical software (SUDAAN, 1996) that incorporates the study-design stratification in variance estimates was used to estimate variances associated with the point estimates. SUDAAN computes variances by first forming the Taylor-series linearization for each statistic, which is then substituted into the formula for computing the variance (appropriate for the study design specified by the user). Incidence (not actually true incidence since cow-years were not part of the denominator) was calculated as the ratio of the weighted sum of the number of cows (or bred heifers) reported with digital dermatitis during the previous 12 months to the weighted sum of the cow (or bred heifer) inventory on the day of the interview. These percentages were interpreted as incidences during the 12-month period, because the clinical course of digital dermatitis in affected cows is usually fairly short (within 21 days) after treatment (Read and Walker, 1998) and we considered all cows to be at risk at the beginning of the 12-month period.

Differences in response rates from the first phase of the study to the digital-dermatitis phase were noted among regions, herd sizes, Dairy Herd Improvement Association (DHIA) participation, and rolling-herd-average milk production – but not among several other variables (including culling rate and cow deaths). Analysis weights were adjusted for nonresponse within each region-herd size-DHIA stratum to account for these differences. This information has been reported previously (National Animal Health Monitoring System, 1997).

2.2. Inferential analysis

The goal of inferential analysis was to identify herd-level factors associated with higher digital-dermatitis incidence, and to evaluate the importance of these factors in the national dairy herd. The outcome variable for inferential analysis was dairy herds with >5% of cow inventory affected with digital dermatitis reported by herd managers in the previous 12 months compared to those dairy herds with $\leq$5% of cow inventory affected. SUDAAN was used to evaluate weighted univariable associations between certain herd-level factors and digital-dermatitis incidence. A chi-square test for independence (adjusted for weights and study design) was used as the screening test and variables with $p<0.1$ were considered eligible for multivariable modeling.

The second step was to evaluate associations using a logistic-regression model, again using SUDAAN. Variables from the initial screening procedure were removed sequentially from the full model using the Wald statistic (because weighted and design-adjusted log-likelihood estimates are not available in this survey-analysis procedure). From coefficients of the final logistic-regression model, odds ratios (as estimates of relative risks) with 95% confidence limits were generated. Parts of this information have been reported previously (National Animal Health Monitoring System, 1997).

The third step was to evaluate the importance of these risk factors using population attributable fraction methods as described by Bruzzi et al. (1985) – similar to methods previously used in a population-based logistic regression analysis (Wells et al., 1996). Upper (and lower) bounds were estimated by computing the population attributable fraction using the upper (or lower) 90% confidence limit of the odds ratio for each

stratum simultaneously (similar to that previously described). Since it is unlikely that each stratum for a variable would be at the highest (or lowest) level at the same time, 90% confidence limits for odds ratios were used instead of 95% confidence limits to estimate upper and lower bounds.

3. Results and discussion

3.1. Data quality

Interviewer and state study-coordinator assessment of producer and field-data quality suggested that overall data quality was satisfactory (Fig. 1). Data from 99.2% of operations were considered high or adequate quality (scores 1–3) based on interviewer assessment of producer responses. Data from 99.7% of operations were considered of high or adequate quality (scores 1–3) based on questionnaire completeness and number of errors.

Producer data quality scores (assessed by interviewer)

Score	% responses	Definition
1	27.3	Producer has a thorough knowledge of the operation and complete information on record. There is no question about the validity of the overall data this producer provided.
2	47.1	Producer has a good knowledge of the operation and has records for most of the needed information. There is little question about the overall data quality this producer provided.
3	24.8	Producer has a fair knowledge of the operation and the information provided seems consistent, although it may not be recorded. Data are based on the producer's best and earnest recollection and knowledge. Records were not consulted.
4	0.8	Producer has little understanding of the operation and the industry in general. Information is inconsistent and often fabricated or based on "wild" guesses.
Total	100.0%	

Field data quality scores (assessed by state study coordinator)

Score	% responses	Definition
1	64.0	Questionnaire is complete, legible, free of errors, and the totals reconcile. Explanations for missing or questionable responses are written on the form. Data can be edited without difficulty.
2	30.2	Questionnaire is complete, legible, contains few errors, and the totals reconcile. Explanations for missing or questionable responses are written but may not be complete. Data can be edited with little difficulty.
3	5.5	Questionnaire contains non-legible responses, incomplete sections, or many obvious errors. A few of the totals do not reconcile, and explanations for missing or questionable responses are missing or not legible. Data are difficult to edit.
4	0.3	Questionnaire is not complete, not legible, contains obvious errors, and totals do not reconcile. Explanations for missing or questionable responses are missing or not legible. Data are difficult to edit and may be discarded.
Total	100.0%	

Fig. 1. Producer and field data quality scores for responses from US dairy operations participating in digital dermatitis questionnaire.

Table 1
Herd size and regional distributions of the incidence of digital dermatitis in US dairy herds, 1996

Variable	Level	Herds with reported cows with digital dermatitis in the previous 12 months (%)	SE
Herd size	<100 cows	36.4%	2.1
	100–199 cows	61.9%	3.5
	200 or more cows	80.3%	2.8
	Total	43.5%	1.7
Region	Northwest	56.1%	4.6
	Southwest	70.3%	3.6
	North midwest	35.4%	2.8
	South midwest	45.5%	4.1
	Northeast	53.1%	3.5
	Southeast	20.8%	5.0

3.2. Descriptive analysis of papillomatous digital dermatitis

In the previous 12 months, 43.5% of US dairy herds reported that cows had shown clinical signs of digital dermatitis. This percentage varied by herd size and region (Table 1). In addition, affected bred heifers were reported on 10.7% of operations in the previous 12 months. Overall, 11.9% of cows and 4.2% of bred heifers were reported affected in the previous 12 months. The recent emergence (or at least recognition) of digital dermatitis as a disease problem was evident: 78.1% of herds reporting digital dermatitis first noted the problem between 1993 and the survey interview in early 1996.

Within positive herds, the average percent of cows affected (18.9%) differed only marginally across herd sizes – whereas larger differences in percentages of bred heifers affected occurred across herd sizes. A high percentage of digital dermatitis-affected cattle were also reported lame (81.9% of affected cows and 85.9% of bred heifers). Yet, not all affected cattle were lame; we acknowledge that additional affected cattle were probably missed – especially if not lame. A recent report from Chile (Rodriguez-Lainz et al., 1996c) indicated that digital-dermatitis prevalence in cows detected at the parlor by examination of feet was typically twice that reported by herd managers.

From the Dairy '96 Study, an estimated 11.9% of cows were reported with clinical signs of digital dermatitis in the previous 12 months, with 81.9% of these affected cows experiencing lameness. Therefore, 9.7% of the US dairy cow population represented experienced digital dermatitis with lameness. This estimate represented 57% of the cows reported as clinically lame (17.2%).

3.3. Inferential analysis of papillomatous digital dermatitis

The distribution of within-herd digital-dermatitis incidence in dairy cows and bred heifers in the previous year is shown in Table 2. A 5% incidence of digital dermatitis was used as the cut-point for inferential analysis. A dichotomous outcome variable was used instead of a continuous outcome measure since within-herd incidence of digital dermatitis

Table 2
Distribution of incidence of papillomatous digital dermatitis in cows and bred heifers in US dairy herds within the previous 12 months, 1995

Cattle affected (%)	Herds reporting digital-dermatitis cases (%)			
	Dairy cows		Bred heifers	
	%	SE	%	SE
0	56.5	1.7	89.3	0.9
0.1–5.0	9.9	1.1	1.7	0.3
5.1–10.0	6.7	0.8	1.9	0.4
10.1–20.0	9.6	1.0	3.2	0.5
20.1–30.0	6.8	0.9	1.3	0.4
>30.0	10.5	1.1	2.6	0.5
Total	100.0		100.0	

was estimated using herd manager observation and reporting rather than by direct measurement by data collectors and also since the reported data were not truly continuous, especially for smaller herds. We chose to use 5% incidence as the cut-point for inferential analysis because our goal was to evaluate risk factors associated with high (>5%) compared to low ($\leq$5%) incidence of digital dermatitis, instead of presence versus absence of reported cases within the herd. Because herds with >5% incidence were more likely to have clinical digital-dermatitis problems, this allowed us to evaluate factors associated with digital-dermatitis problems on dairy operations rather than with presence of the disease. Also, using a 5% cut-point, herds with recognized digital-dermatitis cases in the past that instituted effective on-farm treatment or prevention programs and therefore had a low incidence of clinical disease ($\leq$5% incidence) were not grouped together with high-prevalence herds that have not effectively controlled digital dermatitis. Even in the smallest-sized herds with 30 cows, at least two cows with reported digital dermatitis in the previous 12 months were necessary to be categorized as a high-incidence herd.

Univariable associations between herd-level factors and digital dermatitis are shown in Table 3. Nearly all hypothesized risk factors were associated with a high incidence of digital dermatitis, with the exception of other housing factors (not shown). Association of certain variables with digital dermatitis was indeterminate in terms of cause and effect. For example, both level of hoof trimming and use of footbaths were strongly associated with digital-dermatitis incidence. Because this was a cross-sectional study, however, the temporality of this association could not be assessed. While it is possible that these practices may lead to transmission of digital dermatitis, both of these practices are often implemented as digital-dermatitis treatments. Therefore, these variables were not included in our logistic-regression model – but their roles as causes or effects should be evaluated further in future studies. Use of recycled flush water was not used in the logistic model because of the low frequency of usage on dairy operations. Chemical disinfection of hoof-trimming equipment between cows was not used in the logistic model because stratified analysis showed it was not associated with digital dermatitis after stratification by washing of hoof-trimming equipment between cows.

Table 3
Percent of herds with >5% incidence of papillomatous digital dermatitis (D.D.) and univariable associations, 1995

Variable	Level	Herds with D.D. (%)	D.D. herds with characteristic (%)
Region [a]			
	West	48.4	11.9
	Midwest	29.4	51.8
	Northeast	43.6	34.0
	Southeast	17.0	2.3
Herdsize [a]			
	<100 cows	28.2	64.0
	100–199 cows	51.6	22.9
	200 or more cows	63.2	13.1
Land lactating cows access on daily basis in winter [a]			
	Both pasture and drylot	21.0	6.8
	Neither pasture nor drylot	39.7	29.8
	Drylot only	36.6	61.6
	Pasture only	10.7	1.8
Surface moisture of ground or floor lactating cows stand on most of the time in winter [a]			
	Always wet/standing water	53.5	28.4
	Wet about half the time	33.5	22.8
	Usually dry	28.5	48.8
Predominant flooring type that lactating cows walk on [a]			
	Concrete, grooved	49.2	39.3
	Concrete, textured	23.7	11.1
	Concrete, slat or smooth	32.3	39.7
	Dirt, pasture, or other	23.3	9.9
Flush water used for flushing manure from cow housing areas recycled for multiple flushes [a]			
	Yes	57.6	2.6
	No or no flush water used	33.9	97.4
Freestall housing facility used for lactating cows [a]			
	Yes	48.5	42.0
	No	28.2	58.0
Tiestall or stanchion housing facility used for lactating cows [a]			
	Yes	30.2	54.4
	No	40.7	45.6
Drylot housing facility used for lactating cows [a]			
	Yes	31.4	47.9
	No	37.3	52.1
Percent of cow inventory born off the operation [a]			
	0%	15.9	16.6
	>0 and <25%	39.2	43.7
	25% or more	52.1	39.7

Table 3 (*Continued*)

Variable	Level	Herds with D.D. (%)	D.D. herds with characteristic (%)
Percent of cows that had hooves trimmed at least once in last 12 months [a]			
	0%	11.0	7.8
	1–9%	17.9	12.3
	10–59%	42.2	35.1
	60–100%	64.9	44.8
Does hoof trimmer also trim cattle hooves on other operations [a]			
	Yes	48.3	75.3
	No or no hoof trimming	18.1	24.7
Hoof-trimming equipment routinely washed with water between cows [a]			
	Yes or no hoof trimming	19.2	24.2
	No	45.6	75.8
Hoof-trimming equipment routinely chemically disinfected between cows [a]			
	Yes or no hoof trimming	19.0	21.3
	No	43.7	78.7
Footbath [a]	Used throughout the year	71.4	28.4
	Used only seasonally	52.8	21.9
	Not used	23.6	49.7

[a] $P \leq 0.10$; variable is eligible for multivariable modelling.

Several factors in addition to region and herd size were associated with >5% incidence of digital dermatitis in the final logistic-regression model (Table 4). These factors included: type of land that lactating cows accessed on a daily basis in winter, predominant flooring type where lactating cows walked, percent of cows born off the operation, use of a primary hoof-trimmer who also trimmed hooves on other operations, and washing of hoof-trimming equipment between cows when trimming hooves.

Two factors associated with digital-dermatitis incidence were related to 'cow hoof' environment. Herds where lactating cows had daily outside access only to dry-lot areas during winter were at higher risk of digital-dermatitis incidence (odds ratio (OR)=4.3) and those where lactating cows had daily access to neither dry lots or pasture were at intermediate risk (OR=2.6), compared to the reference population where lactating cows had daily access only to pastures. This analysis suggested that high incidence of digital dermatitis could be prevented in 69% of dairy operations (Table 5) if all herds allowed daily access only to pasture.

A second environmental factor associated with digital-dermatitis incidence was flooring type. Herds where the predominant flooring type where lactating cows walked was grooved concrete were at highest risk (OR=2.7) compared to the reference population of herds with textured-concrete flooring. Also at higher risk were herds where the predominant flooring type was smooth or slatted concrete (OR=1.8).

Table 4
Risk factors for >5% papillomatous digital dermatitis within-herd incidence for US dairy herds, 1995

Variable	Level	Odds ratio	95% CL
Region			
	West	1.7	0.8–3.9
	Midwest	1.8	0.8–4.0
	Northeast	3.4	1.5–7.8
	Southeast	1.0	—
Herd size			
	<100 cows	1.0	—
	100–199 cows	2.0	1.4–3.0
	200 or more cows	2.7	1.7–4.5
Land lactating cows access in winter			
	Both pasture and drylot	2.0	0.8-4.9
	Neither pasture nor drylot	2.6	1.1-6.3
	Drylot only	4.3	1.9-9.7
	Pasture only	1.0	—
Predominant flooring type on which lactating cows walk			
	Concrete, grooved	2.7	1.5–4.7
	Concrete, textured	1.0	—
	Concrete, slat or smooth	1.8	1.0–3.1
	Dirt, pasture, or other	1.2	0.6–2.4
Percent of cow inventory born off the operation			
	0%	1.0	—
	More than 0 and less than 25%	4.1	2.6–6.3
	25% or more	7.9	4.9–13.0
Hoof trimmer also trims cattle hooves on other operations			
	Yes	2.8	1.9–4.2
	No or no hoof trimming	1.0	—
Hoof-trimming equipment routinely washed with water between cows			
	Yes or no hoof trimming	1.0	—
	No	1.9	1.2–2.8

Causative mechanisms through which these two factors lead to increased digital-dermatitis incidence might include concrete's abrasive properties, slipperiness, and other factors associated with hoof environment and flooring (such as cow housing and cow-movement patterns). One potential mechanism, however, through which both of these environmental factors may predispose dairy herds to higher incidence of digital dermatitis is related to exposure of hooves to continual moisture and poor hoof hygiene. Moisture softens hooves which leads to increases in wearing and may lead to hoof abrasions (which could provide entry points for microorganisms). Stall moisture has been previously associated with lameness prevalence in Wisconsin and Minnesota herds (Wells et al., 1995). Rodriguez-Lainz et al. (1996b) reported an association between

Table 5
Population attributable fractions for digital-dermatitis risk factors for US dairy operations, 1995

Variable	Population attributable fraction	Estimated lower and upper bounds
Region	0.52	0.09–0.75
Herd size	0.20	0.13–0.25
Land lactating cows access in winter	0.69	0.39–0.84
Predominant flooring type on which lactating cows walk	0.43	0.15–0.61
Percent of cow inventory born off the operation	0.68	0.60–0.73
Hoof trimmer also trims hooves on other operations	0.48	0.37–0.56
Hoof-trimming equipment routinely washed with water between cows	0.35	0.18–0.47

digital-dermatitis incidence and corral moisture in southern California dairy operations with dirt drylot corrals. In that study, muddiness of the feed bunk and cow loafing areas after rains was evaluated by hoof trimmers, herd veterinarians, and herd managers to assess moisture. In the NAHMS Dairy '96 Study, moisture levels (as evaluated by herd managers) were associated with digital-dermatitis incidence in the univariable analysis – but not after adjusting for the effects of other variables. One reason for the difference in findings between the studies was the availability of data from moisture assessments by herd veterinarians and hoof trimmers in the California study. Veterinarians and hoof trimmers may have better reference bases for assessing relative moisture levels than herd managers (because the former visit many operations on a regular basis).

The percent of cows born off the dairy operation was strongly associated with high digital-dermatitis incidence, and there was evidence for a dose-response relationship. Rodriguez-Lainz et al. (1996b) showed a strong association between introduction of heifers and digital-dermatitis prevalence in southern-California dairy herds. Our current NAHMS study supports that finding on a national scale – suggesting that digital dermatitis is initially brought onto dairy operations by affected cows or heifers introduced from other herds. Population attributable fractions showed that >5% incidence of digital dermatitis could be prevented in 68% of herds if all herds were closed to introduction of cows or heifers. It is also possible that introduced cattle or heifers may have been more susceptible to infection than those already on the operation. While introduction of cattle is unavoidable on most dairy operations, effects of introduction of affected cattle might be reduced by other means (such as careful screening of introduced cattle to prevent disease entry).

This study, part of the NAHMS Dairy '96 Study, identified two other biosecurity factors related to digital-dermatitis incidence. Herds where the primary hoof trimmer also trimmed cows' hooves on other operations were 2.8 times more likely to have >5% incidence of digital dermatitis (compared to herds where the primary hoof trimmer did not trim hooves on other operations or where cows' hooves were not trimmed). The population attributable fraction was 48%. This association was not confounded by herd size. While larger-sized herds were more likely to have used a primary hoof trimmer who

also trimmed hooves on other operations, stratified analysis (results not shown) showed that the relationship between use of a hoof trimmer who trimmed cattle on other operations and digital-dermatitis incidence was consistent across herd sizes. Also, herds where hoof-trimming equipment was not washed between use on cows were 1.9 times more likely to have >5% incidence of digital dermatitis than those where the equipment was washed or where no hooves were trimmed (population attributable fraction=35%). We recognize that bringing a hoof trimmer on the operation that also trimmed cows on other operations might have been an effect rather than a cause; nevertheless, that these associations indicate potential transmissibility among cows via fomites (e.g., hoof-trimming equipment) emphasizes the contagious nature of this disease and the importance of breaking the chain of transmission through sanitation practices by hoof trimmers and others.

Although region and herd size were associated with digital dermatitis, these variables are surrogates for variations in management practices (such as feeding practices and housing systems, climate, and other environmental factors) not directly evaluated in this study. Large herds were more likely to report >5% incidence of digital dermatitis than small or mid-sized herds. Although the West region had the highest incidence (Table 4), the region with the highest adjusted risk of digital dermatitis was the Northeast. This finding was one indication that the variation in digital-dermatitis incidence in the Northeast (compared to that in the West) was not explained as well by other variables in the model.

One limitation of this study was that reporting of digital dermatitis relied upon retrospective assessments of disease occurrence by herd managers. Many digital dermatitis cases go unrecognized on dairy operations (Rodriguez-Lainz et al., 1996c). Also, some cases of disease are likely to be forgotten through time by producers. This reporting bias could influence risk-factor analysis if it changed the digital-dermatitis status of the herd. Because our goal was to evaluate risk factors associated with problem herds (using >5% incidence as the cut-point), we considered the level of misclassification to be acceptable for this analysis – it provided a means (for analysis purposes) to separate those herds without recognized cases or with controlled digital dermatitis ($\leq$5% incidence) from herds with higher incidence. Another limitation was the inherent weakness of cross-sectional studies in evaluating associations rather than true causation. As such, we consider the value of this risk factor study is the generation of hypotheses for future study.

Strengths of this analysis were the broad geographic distribution of dairy herds representing the various management systems used by dairy producers across the USA and the random sampling of producer participants – both of which allowed generalization to the US dairy herd population. This analysis supported previous research showing the association between introduction of cattle and digital dermatitis. In addition, other biosecurity concerns (including washing hoof-trimming equipment between cows and hoof trimmers who trim cattle hooves on multiple operations) and environmental factors (flooring type and daily access to outside areas) were identified. These factors need to be considered in digital-dermatitis-control efforts and evaluated in further research.

4. Conclusion

Based on results from this study, dairy managers should consider their biosecurity programs and 'cow hoof' environment while assessing digital-dermatitis control plans. Specific biosecurity management considerations include introduction of noninfected cattle to the operation when purchasing decisions are made and avoidance of fomite transmission through strict sanitary procedures during the hoof-trimming process.

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